NASA-CR-197456

FINAL
IN-70-CR
OCIT
33543
3P

The University
Of Alabama
In Huntsville

NAG8-874

[redacted]

Final Report

The performance of this Grant produced considerable insight into the MHD processes occurring in the solar atmosphere that lead to major solar flares. The work carried was adapted to the findings of previous stages of the research. We can summarize the following milestones:

A) From theoretical analysis we achieved the following new results:

a) We have found an alternative MHD analysis that bases in studying the behavior of the electric currents in the upper atmospheric layers to asses the MHD evolution of these layers. This behavior is the response to evolution due to the magnetic fields resulting from electric currents in sub-photospheric layers (plasma-beta larger than unity), and their interaction with the thermodynamics of the plasma at and above the photosphere (plasma-beta unity and below).

b) We developed an alternative method for evaluating the local magnetic energy storage. This method is based in the local currents and describes the self- and mutual-energy of the current systems above the photospheric boundary. This method is also able to describe well the interaction energy between the currents above and below the boundary.

B) From observational analysis we achieved the following new results:

c) We found that although magnetic "shear" and/or the vertical electric currents exist in flaring regions, their magnitudes are not good indicators for likelihood of an X-class flare.

d) We found that the horizontal motions observed in a region that experienced two large X-class flares did not conform the usual shear pattern that has been proposed to power flares.

e) We found that rather a new shear pattern occurs in which the velocities are maximum near the polarity reversal line, and that has a very particular pattern of vertical current at the location of maximum horizontal velocity.

f) We found that the magnitudes of the horizontal Lorentz forces near the polarity reversal line, and the fact that they are consistent with the building of magnetic-free energy above the photosphere in the region that later experiences X-class flaring.

g) However, we found that the total magnetic free-energy built as consequence of the previously mentioned storage is barely enough to power the observed flares.

h) Therefore, we found that is likely that the current observations of vector fields at the photospheric level are incapable of revealing the main buildup of magnetic-free energy.

i) We found that at least in one case the appearance of a magnetic field null above the photosphere seems related to the start of flare activity in a region that did not experience flaring before.

C) From further theoretical analysis we achieved the following results:

j) The effects of reconnection of magnetic fields at nulls with moderate gradient of the magnetic field is rather tiny because of the effects of gas pressure that dominate the dynamics close to the null.

k) Therefore buildup of current sheets, large pressure gradients, and high-speed flows along the field lines near the separatrices would occur.

l) These effects become non-linear much before dissipation occurs and may produce large turbulence and energy dissipation near the separatrices, when certain changes of the field are driven by the boundaries.

m) These effects were largely underestimated by very expensive numerical simulations because of the limited grids and artificial dissipation introduced in these calculations.

n) The local magnetic free-energy stored in the current sheets near the separatrices is most likely dissipated by the breaking apart and ejection of the fragments of the electric currents. It is unlikely that much of the currents is dissipated by Joule effect.

As is shown above, our research led to solid advances in our understanding of the origin of solar flares. This advancement was done by both, ruling out processes and discovering new processes. As our studies showed the current type of observations of the vector magnetic field in the photosphere, by using optical or infrared lines, although important are incapable of giving a final answer to the question of the magnetic origin of flares. Rather, we need to observe the vector fields at both the photosphere (where plasma-beta is near unity) and at the high chromosphere (where plasma-beta is much smaller than unity), in order to find out the necessary information to understand the origin of solar flares. This understanding is a pre-condition to an accurate prediction of occurrence and magnitude of flare activity.

The development of the research

Our research was carried using three basic tools, the development of a new formulation for the MHD problem posed by flare activity, the analysis of MSFC vector magnetograph data on a flaring region, the application of our previous new formulation to the problem of magnetic field nulls. All these tasks were carried by the PI, and the observational part involved collaborators from MSFC and from Hungary (these provided with high resolution data and analysis of sunspot motions).

Most of the results obtained are published, ApJ 419 p.837-854, ApJ in press. We enclose copies of these papers that explain in more detail the results we summarized above. We note that the publication of these papers takes considerable time because of the delay of the exchanges with the editors and referees, and because of the delays in the actual printing process at ApJ.

We also enclose copy of the latest research done under this Grant, this last part has not been yet published. This last research consisted in the extension of our study of magnetic field nulls to a three-dimensional case. This extension is quite difficult because of the complex vector mathematical expressions involved and the need to use curvilinear coordinates in a non-planar case. However, we have made significant progress in this respect in spite of the limitations of the current Grant. This progress is of great importance because the three-dimensional case is far closer to reality than the previous two-dimensional cases, essentially different phenomena occurs in three-dimensions that is made impossible by the two-dimensional setup, the energies become finite instead of the unrealistic infinite energies of the two-dimensional cases, the treatment of realistic three-dimensional nulls including gas pressure is even further away from the possibilities of any current numerical simulation approach. All these factors make the theoretical analysis of three-dimensional nulls a major challenge for which we obtained significant progress in formulating and approaching the solution.

We have not found major difficulties in our research beyond the expected difficulty of finding new approaches that led to progress in this research. Practical difficulties did not appear, and the research proceeded smoothly.

We want to thank the exchange of ideas with all members of MSFC that helped to produce an important breakthrough in this field. We believe that this exchange of ideas is crucial for the progress in any field because a closed research environment does not permit to test our own ideas against other people experience with similar or diverse ideas and procedures. Our research has also benefited from exchange of ideas with other scientists from other centers through a few trips to scientific meetings, where we presented preliminary results of our research.

J.M. Fontenla
Principal Investigator
August 9, 1994